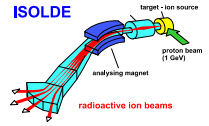


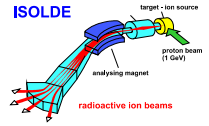
Challenges for light nuclei

Karsten Riisager – PH Department, CERN

+ ideas by Hans Fynbo – Univ. of Aarhus

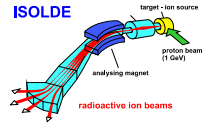
Nuclear physics research at the MYRRHA accelerator
April 7, 2008

Favoured experiments



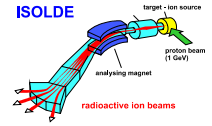
- High-precision experiments
- Experiments looking for small signals
  - small decay branches
  - small reaction cross sections
- Experiments with an inherent low efficiency

Beams – equipment



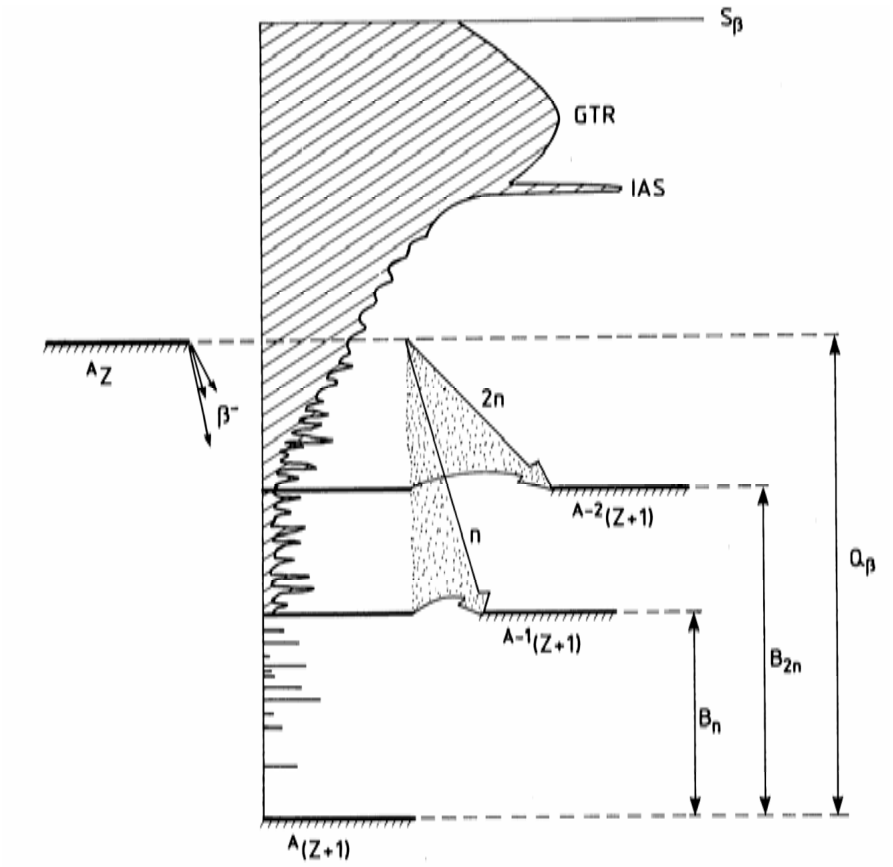
- Alkali and gaseous elements
  - assume: He, Li, Ne, Na, ...
  - perhaps C, N, ...
  - other elements ?
- Decay spectroscopy (beta-decay)
  - implant in catcher foil / detector – trap
  - polarized beams ? Ex. ^{11}Li Hirayama et al, PL B611 (05) 239
  - detectors for β, γ, charged particles, n
- Reactions ??!
  - astrophysics, p capture – n capture ?

Interest in small decay branches ?



- Decay rate $\lambda \approx f \times |M|^2$
  - branching ratio = λ / λ_{tot}
- Beta-decay f-factor $\approx (Q\text{-}E)^5$ or $(Q\text{-}E)^2$
  - transitions with large strength to high E
- Allowed / first forbidden / ...

Gamow Teller Giant Resonance

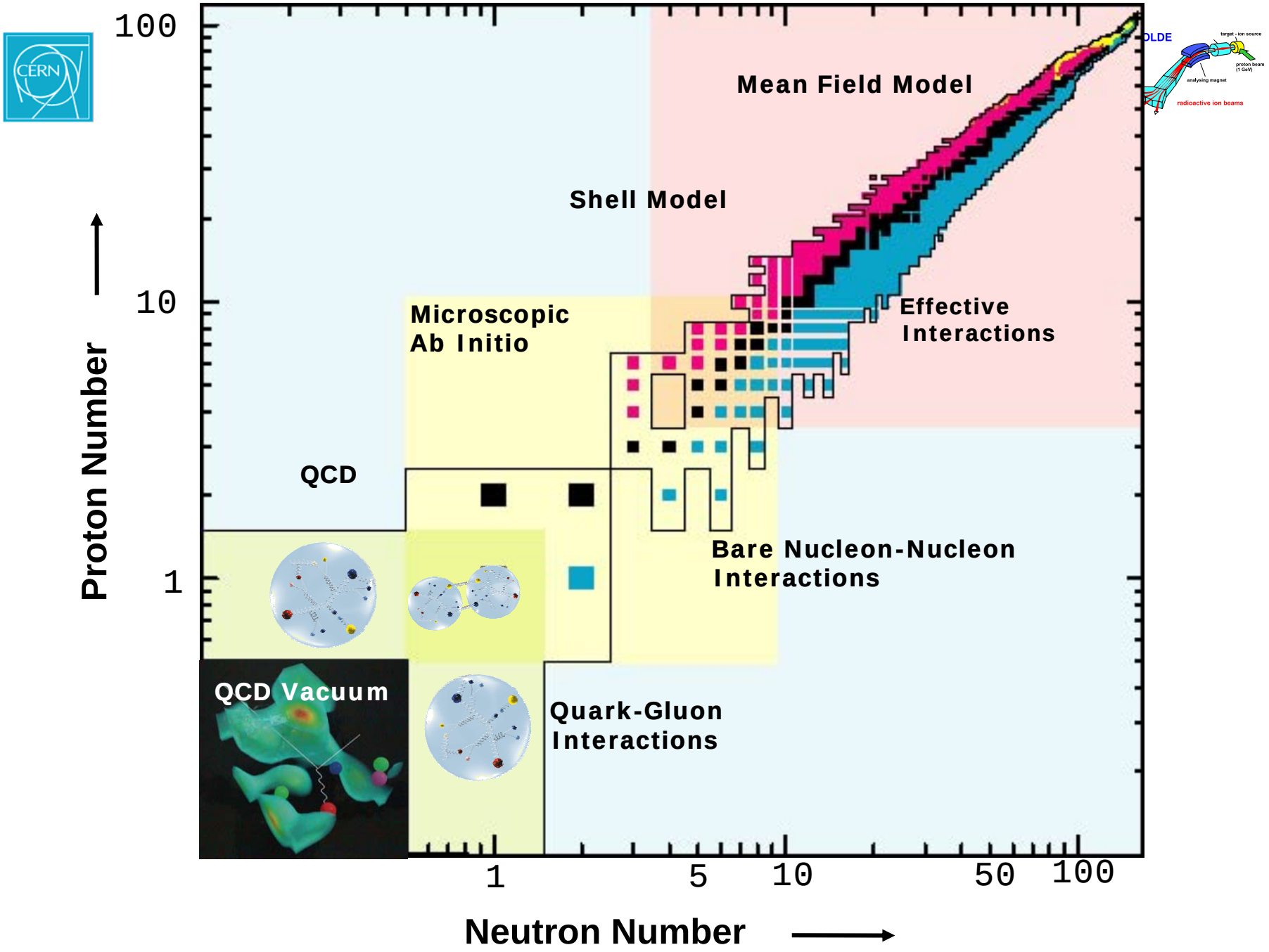


From: P.G. Hansen and B. Jonson, p. 157 in Particle emission from nuclei, ed. M. Ivascu and D. Poenaru, vol. III (CRC Press, 1988)

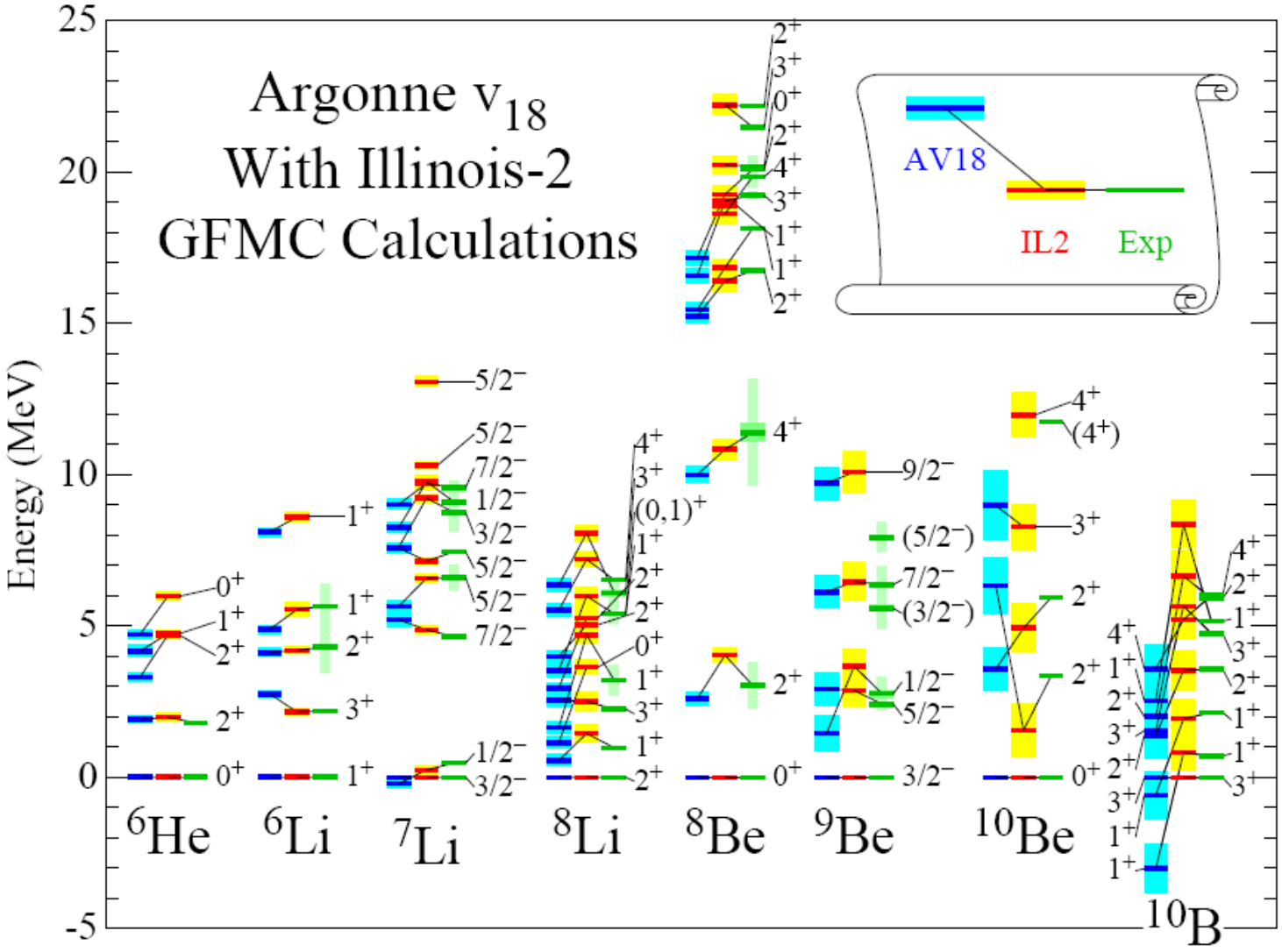
Large B_{GT} corresponds to large structural overlap

Tests of sum-rule with GTGR – see e.g.

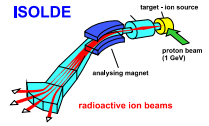
M.J.G. Borge et al,
Z. Phys. A332 (1989) 413


100
10
1
Proton Number
Mean Field Model
Shell Model
Microscopic
Ab Initio
Effective
Interactions
QCD
Bare Nucleon-Nucleon
Interactions
QCD Vacuum
Quark-Gluon
Interactions
1
5
10
50
100
Neutron Number
OLDE
target - ion source
proton beam
(1 GeV)
analysing magnet
radioactive ion beams

Quantum Monte Carlo calculations



Other theory approaches

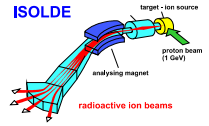


- Shell Model embedded in the continuum
  Okołowicz, Płoszajczak, Rotter, Phys. Rep. 374 (2003) 271

- Generator Coordinate Method, Lagrange-mesh etc e.g. Descouvemont, Daniel, Baye, PR C67 (2003) 044309

- Few-body models Nielsen, Fedorov, Jensen, Garrido, Phys. Rep. 347 (2001) 373

Beta-delayed particle emission



β^- (similar for β^+)

N-5	N-4	N-3	N-2	N-1	N	
$\beta 4n$	$\beta 3n$	$\beta 2n$	βn	β		Z+1
		βt	βd	βp		Z
		$\beta \alpha$				Z-1

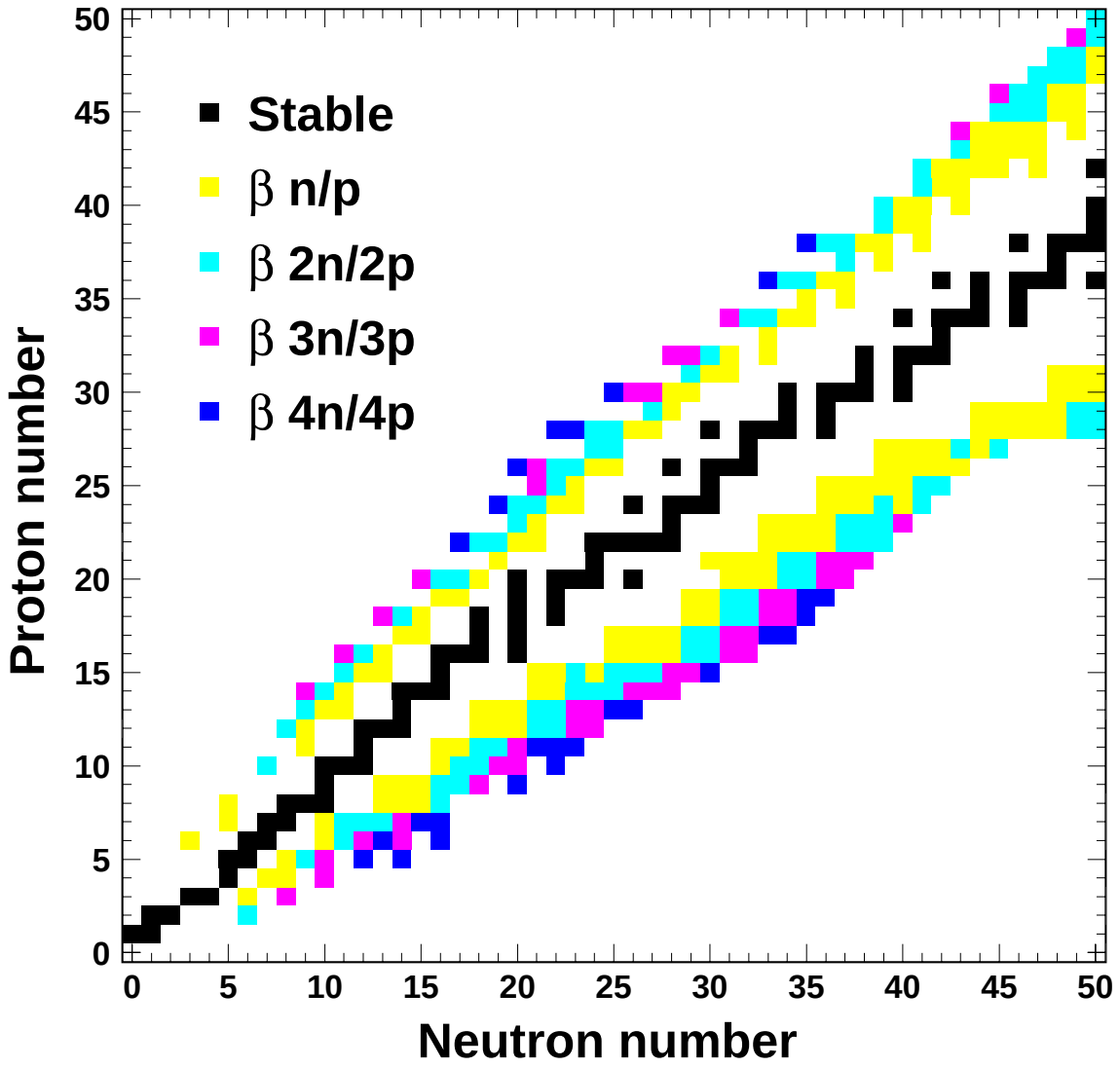
$Q_{\beta p} = 0.782\ \text{MeV} - S_n$

$Q_{\beta d} = 3.007\ \text{MeV} - S_{2n}$

$Q_{\beta t} = 9.264\ \text{MeV} - S_{3n}$

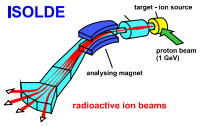
B. Jonson, K. Riisager, NP A693 (01) 77

Energetically allowed decays (1)



Experimental masses

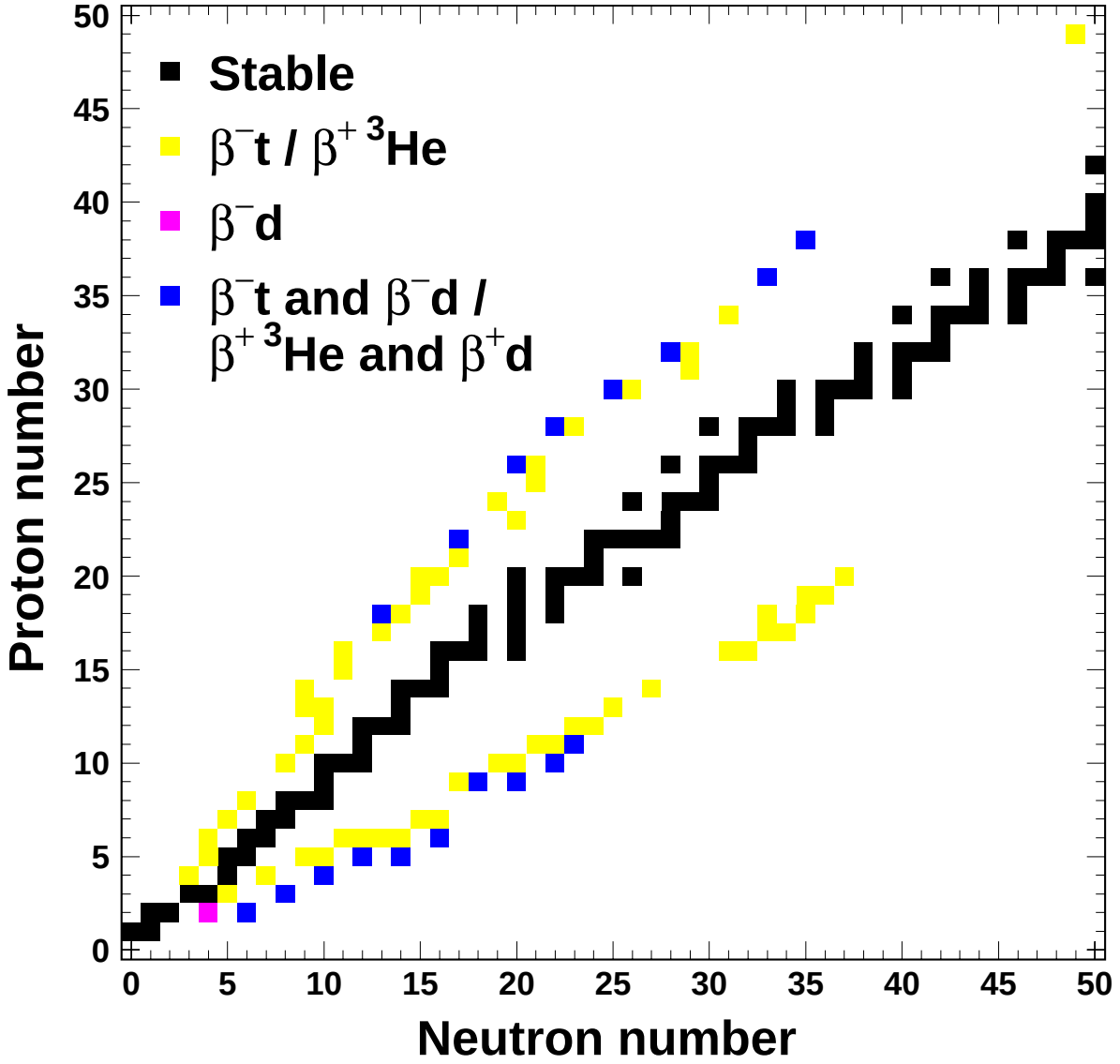
Detailed studies of βxn/p ?



- Case of ^{31}Ar:
  - from βp as much info on ^{30}S as from "stable beam exp" H.O.U. Fynbo et al, NP A677 (2000) 38
  - determine p/γ competition ? – seen p from 5.217 MeV level, not from 5.136 MeV...

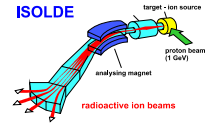
- Multi-particle emission
  - for β2p only detailed study for ^{31}Ar
  - for β2n etc. **very** limited information – cases: ^{11}Li, ^{19}C, $^{30\text{-}34}$Na, ^{52}K, ...

Energetically allowed decays (2)



Experimental masses

Why interest in these decays ?

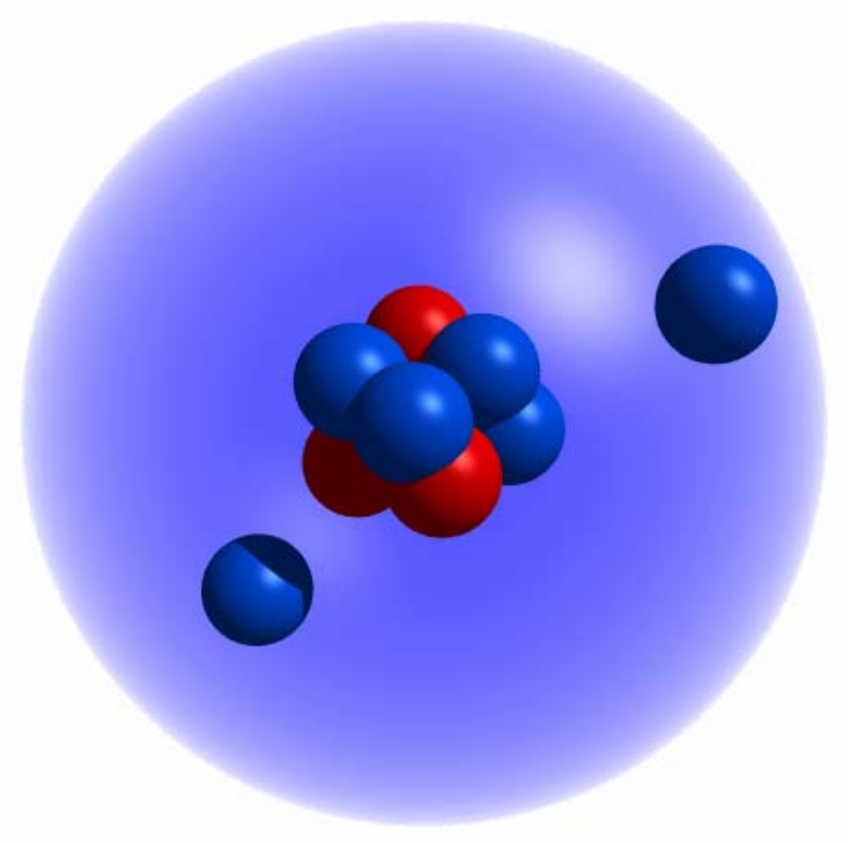


- If visible, they correspond to large B_{GT} (superallowed decays – Borge et al, Z. Phys. A340 (1991) 255)

- If going through resonances: typically large $\Gamma_{particle}$, an important facet for understanding their structure (mother + daughter state !)

- Possibly decays directly to continuum

Decays directly to continuum ?

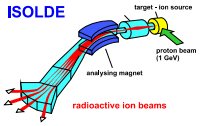


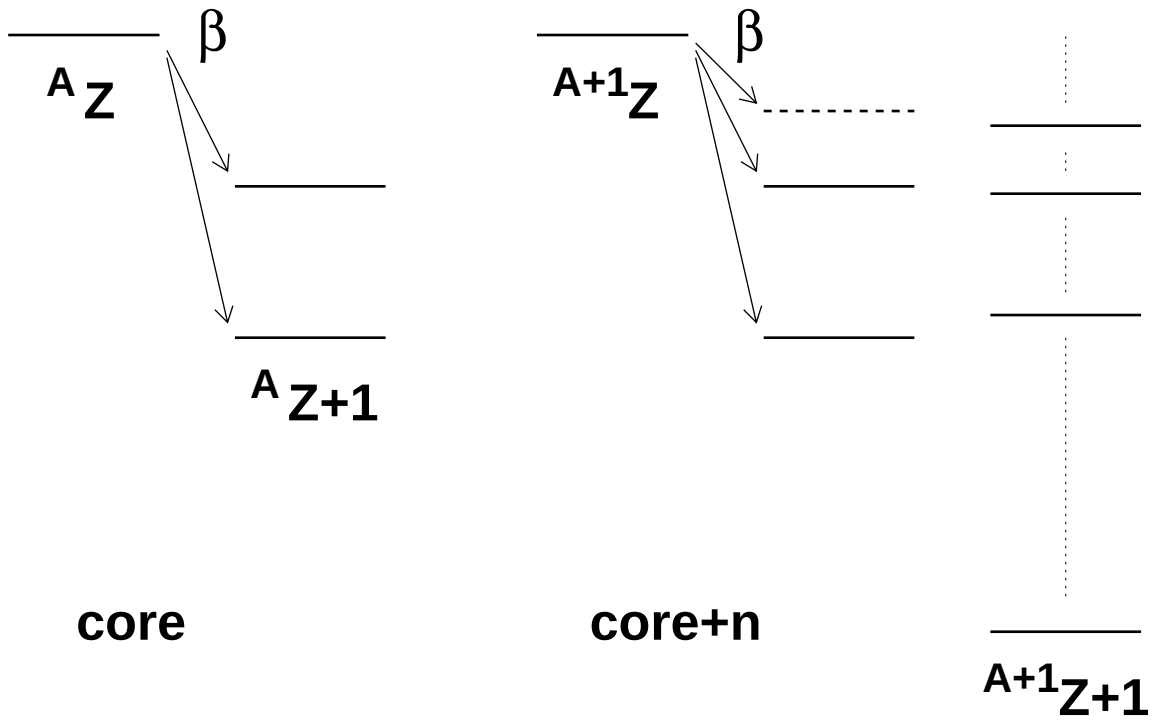
Naive picture: outside of normal nucleus
sensitive to correlations

Many theory papers confirm direct decay as appropriate model, e.g.:

Zhukov et al, PR C47 (93) 2937
Baye et al, Prog.T.Phys. 91 (94) 271
Barker, PL B322 (94) 17
Zhukov et al, PR C52 (95) 2461
Ohbayasi et al, PL B346 (95) 223
Baye et al, PR C74 (06) 064302

“Halo” decays in cluster picture





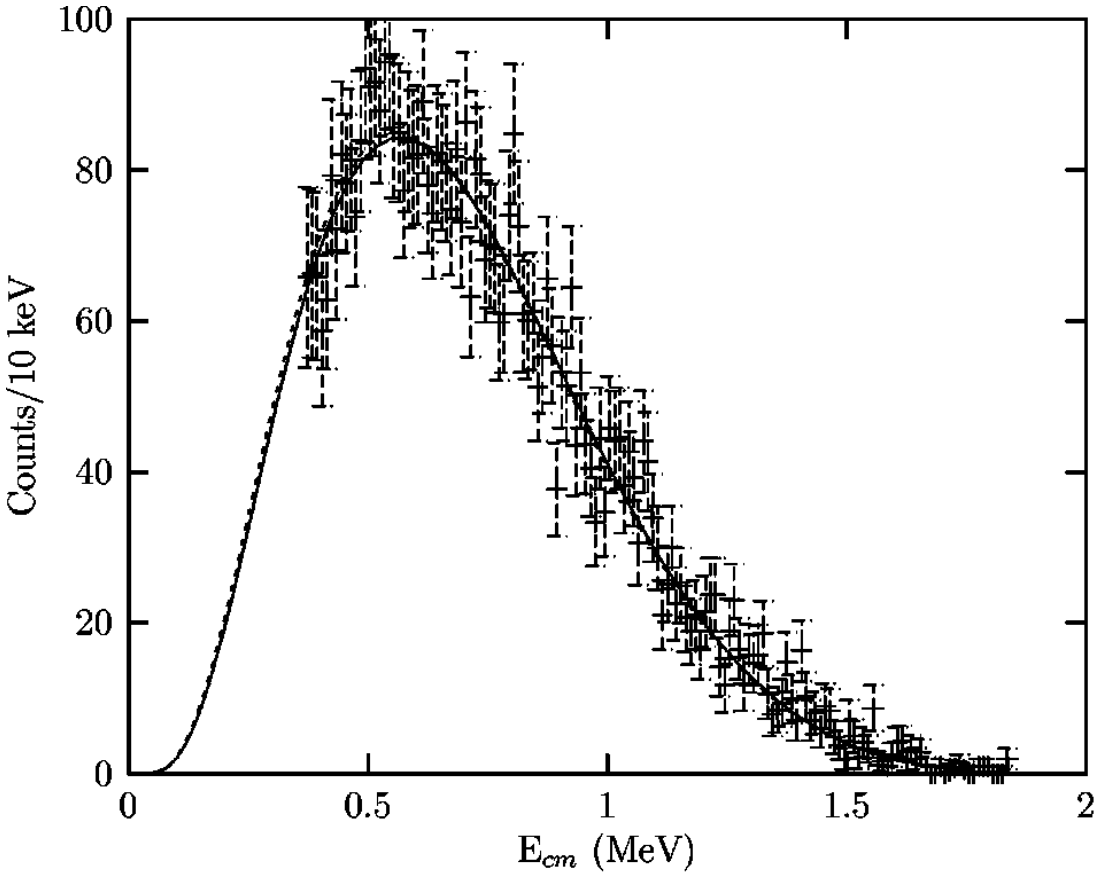
$O_\beta|\text{halo state}\rangle = O_\beta(|\text{core}\rangle|\text{halo}\rangle) =$
$(O_\beta|\text{core}\rangle)|\text{halo}\rangle + |\text{core}\rangle(O_\beta|\text{halo}\rangle)$

→ “halo strength” at high excitation energy

T. Nilsson et al, Hyperfine Int. 129 (2000) 67

Present status – ^{6}He(βd)

Anthony et al., PR C65 (02) 034310
(also: Smirnov et al, NIM A547 (05) 480)

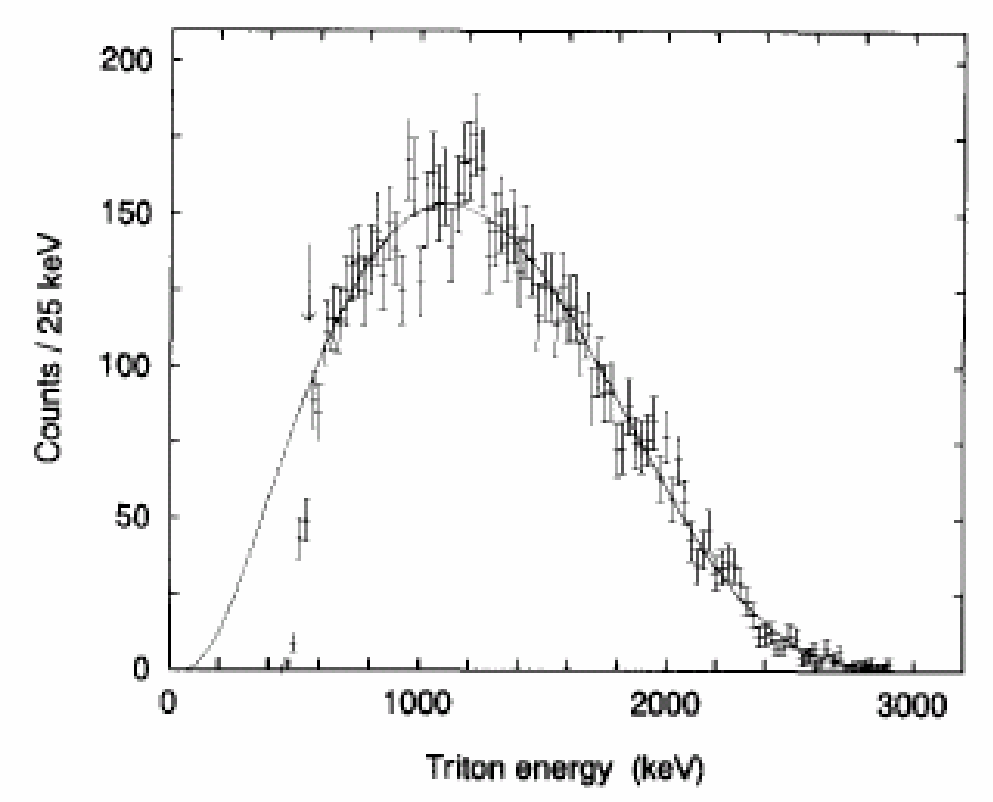


Intensity around 10^{-6}.
Proceeds directly to continuum states.
Very sensitive to theoretical assumptions.

Possible improvements:
low-energy tail
(better resolution)

Present status – ^{8}He(βt)

Experiment: Borge et al, NP A560 (93) 664
R-matrix fit: Barker, NP A609 (96) 38



Intensity almost 10^{-2}.
Few-body model:
Grigorenko et al, NP A607 (96) 277 + A614 (97) 567

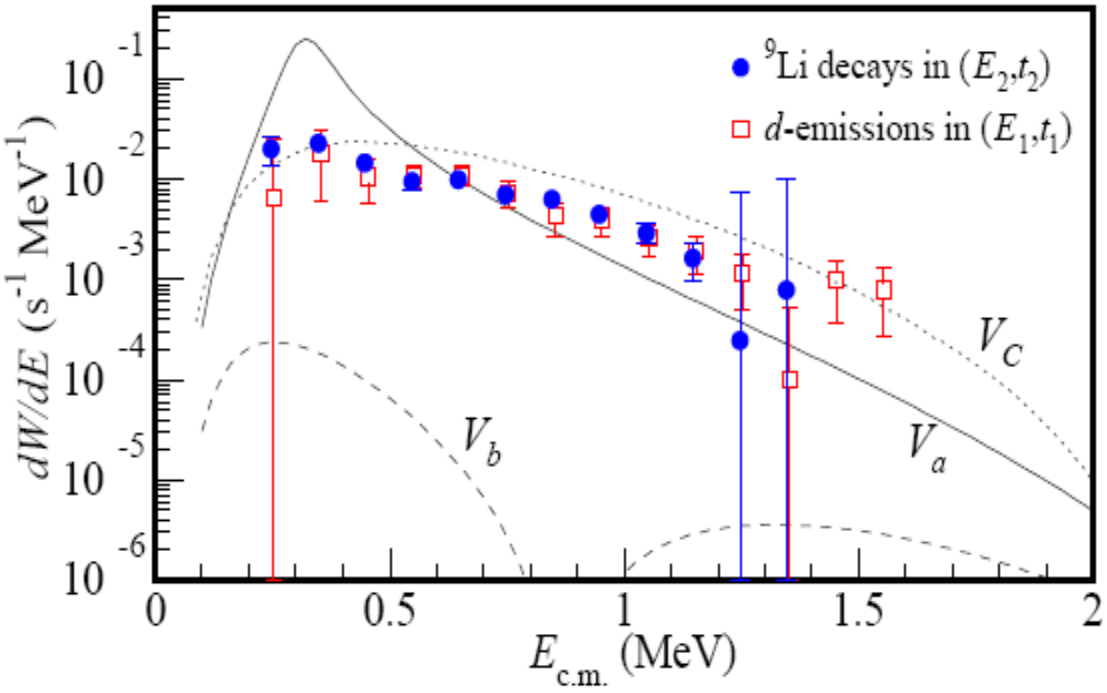
Possible improvements:
low-energy tail
decay mechanism
NB ! "Missing strength" perhaps in β2n channel, intensity 10^{-5} – 10^{-4}, cf.
Shul'gina et al, NP A619 (97) 143

Present status – ^{11}Li(βd/βt)

Latest experiment: R. Raabe et al, PRL submitted

Both branches have intensity above 10^{-4}

βd decay to continuum



Possible improvements:

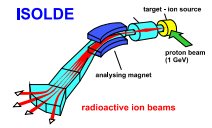
statistics !!

cross-check result

low-energy tail

interpretation of βt

Potential new branches

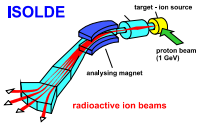


- ^{8}He – beta-delayed deuterons / 2n ?
  - $Q_{\beta d}$ = 0.867 MeV, Q_{2n} = 1.37 MeV

- ^{11}Li – beta-delayed pn emission ?
  - $Q_{\beta pn}$ = 0.41 MeV, continuum decay

- New isotopes:
  - βt ^{29,30,32}Ne, ^{32,33,34}Na; βd ^{32}Ne, ^{34}Na

Forbidden transitions...



- ^{8}Li, 2nd forbidden to ^{8}Be g.s.
  - ^{8}B: branching ratio < 7.3×10^{-5}, theory predicts (1-20)×10^{-6} Bacrania et al, PR C76 (07) 055806
- ^{11}Li, 1st forbidden to ^{11}Be g.s.
  - tests p/s ratio in halo Borge et al, PR C55 (97) R8
- ^{9}Li, 1st forbidden to ^{9}Be(1/2^{+}) at 1.68 MeV
  - 110 keV above threshold, width 217 keV, i.e. asymmetric shape, studied via (e,e') Kuechler et al, Z. Phys A326 (87) 447
- ^{6}He, 2nd forbidden to ^{6}Li(3^{+}) at 2.18 MeV ?

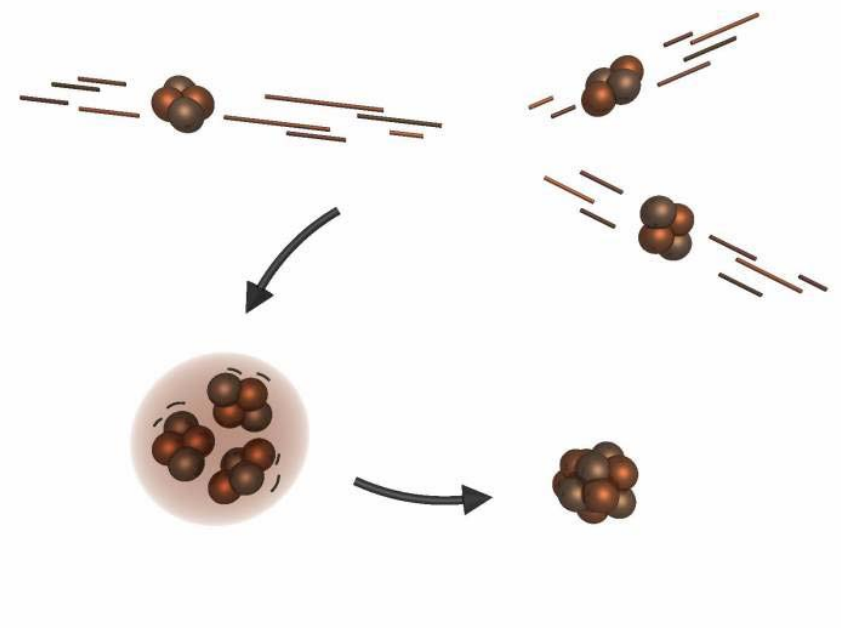
Other cluster studies

^{12}C – 3 α's
decay of ^{12}N/B

^{13}N/C – add nucleon
decay of ^{13}O/B

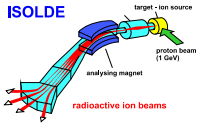
^{16}O – 4 α's / ^{12}C+α
decay of ^{16}N

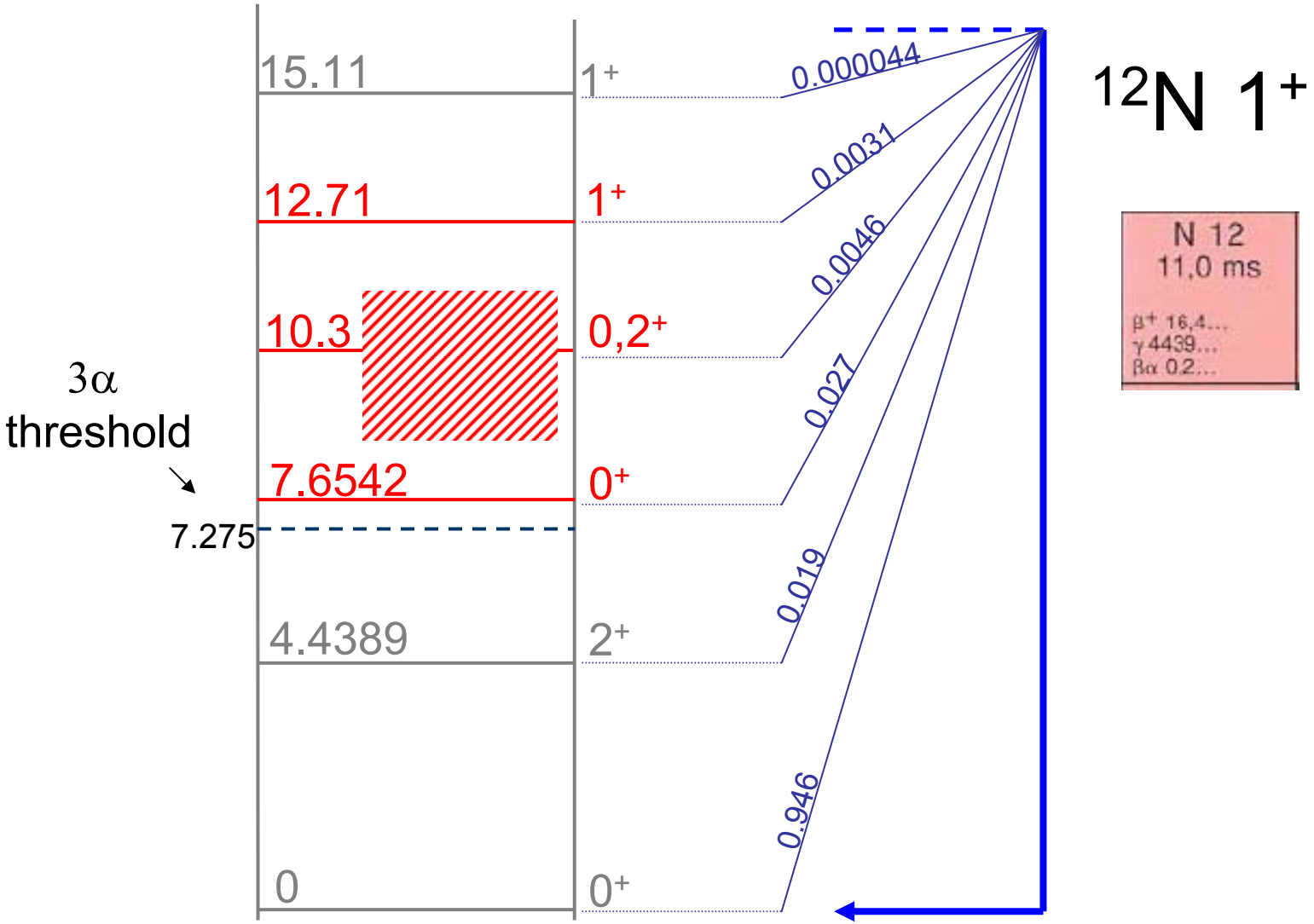
Multi-particle states
Isospin symmetry ?



^{12}C continuum needed
for triple-α process
Fynbo et al, Nature 433 (05) 136
Diget et al, NP A760 (05) 3

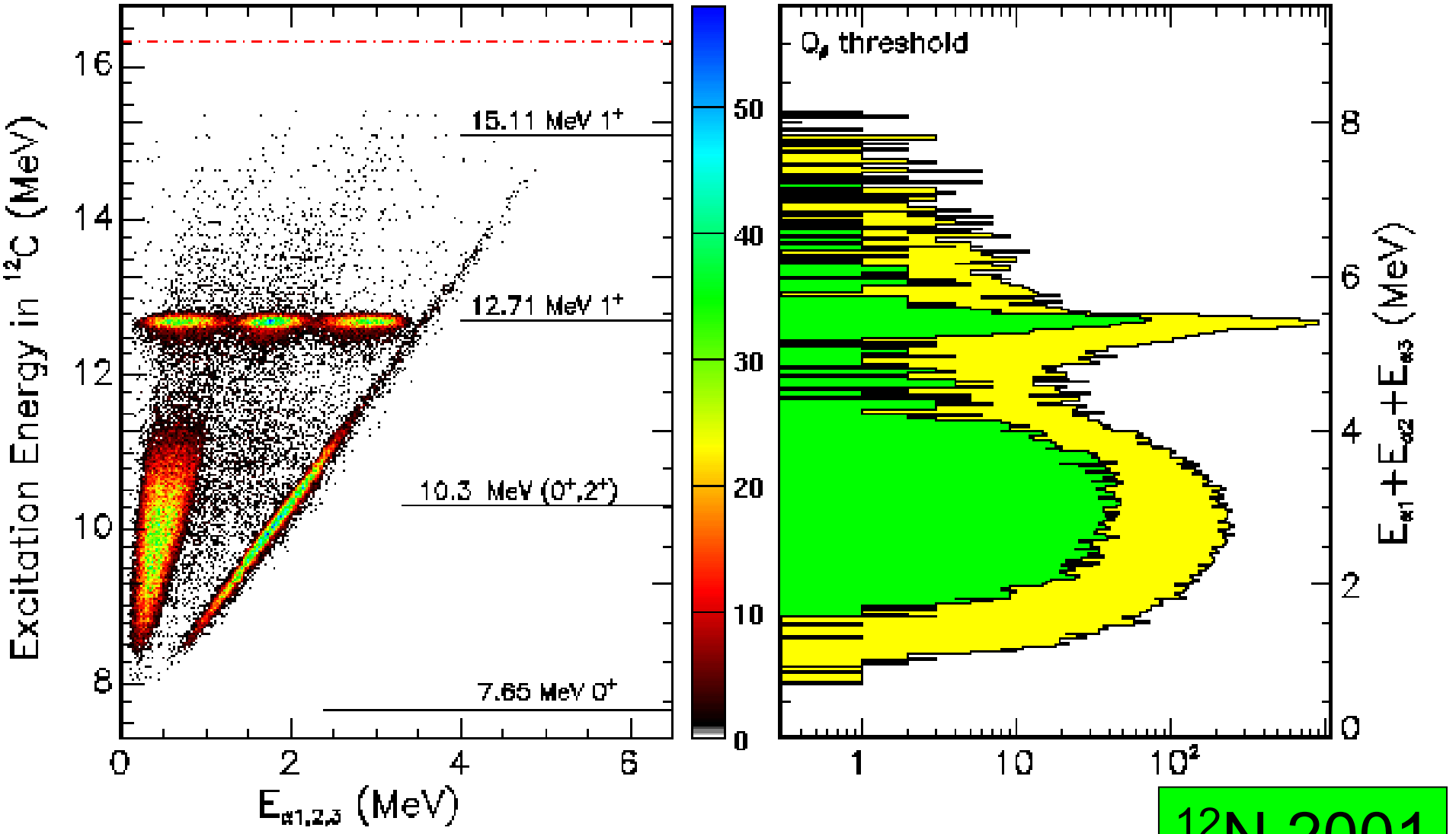
The β-decay of ^{12}N





IGISOL 2001, 2004

Triple-alpha coincidence data

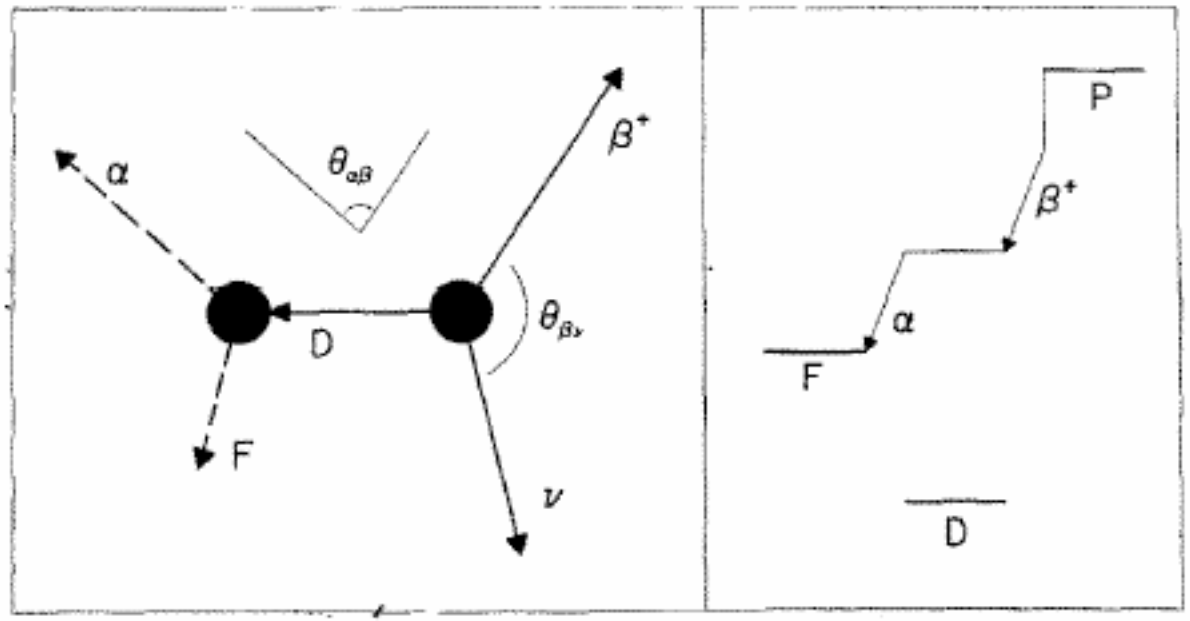


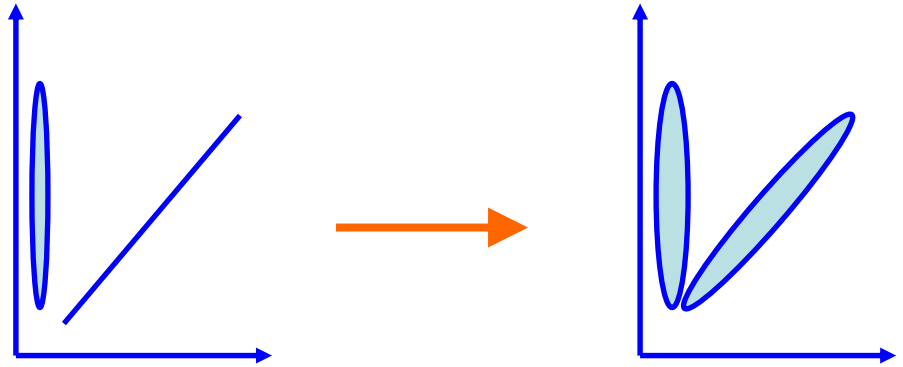
^{12}N 2001

^{12}N 2004

Use of β-decay for spin-determination?

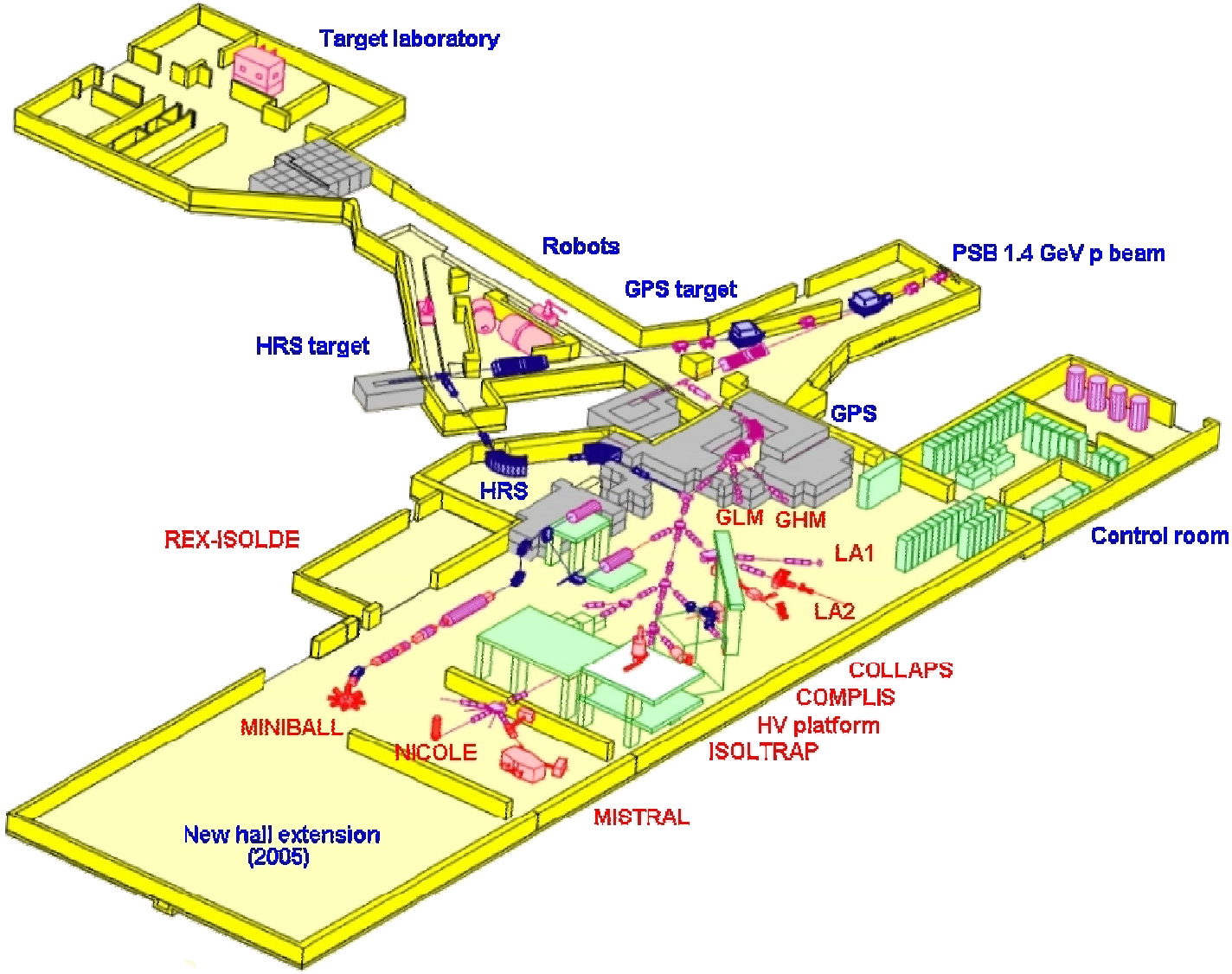
^{8}Be ^{12}C $^{12}N/^{12}B$



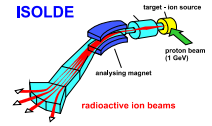


Method used for ^{8}B decay by A. Garcia *et al.* (Seattle) – 2nd class currents

ISOLDE@CERN

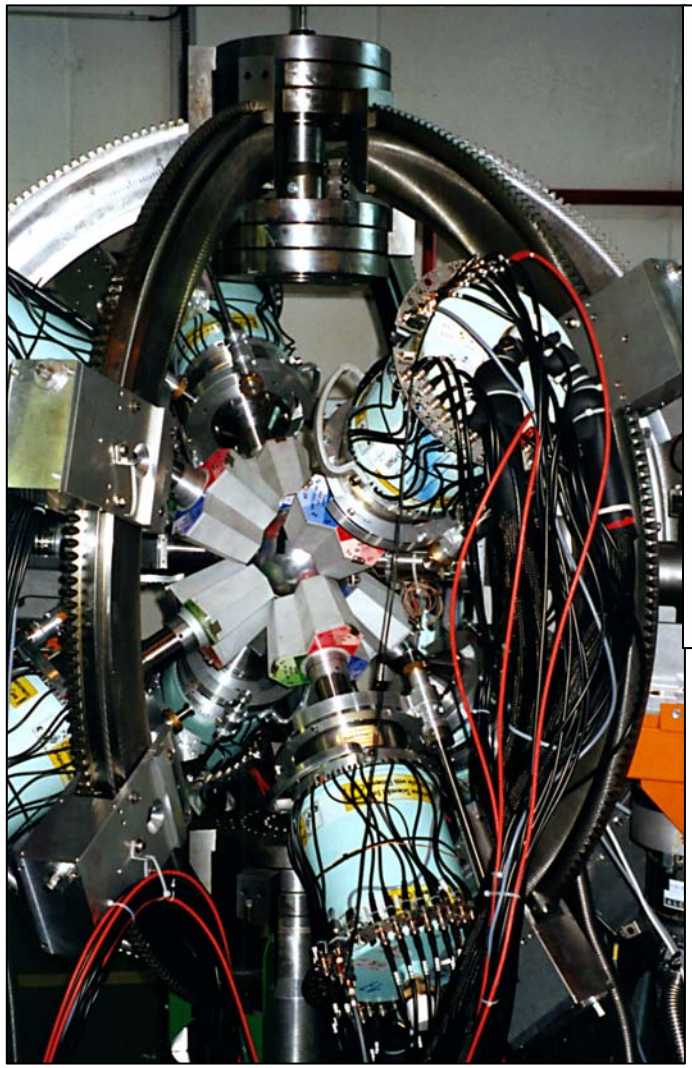

Target laboratory
Robots
PSB 1.4 GeV p beam
GPS target
HRS target
GPS
HRS
GLM
GHM
REX-ISOLDE
Control room
LA1
LA2
COLLAPS
COMPLIS
HV platform
ISOLTRAP
MINIBALL
NICOLE
MISTRAL
New hall extension
(2005)

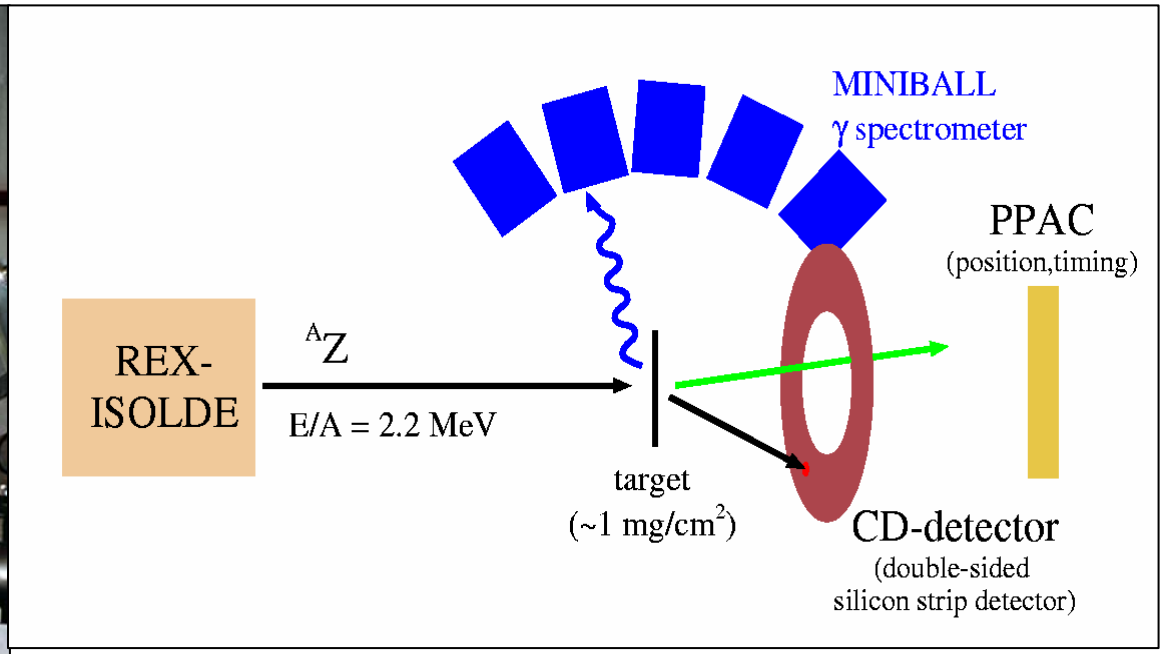
An example: $^{30\text{-}33}$Mg



- 2^{nd} 0^+ in ^{30}Mg at 1788 keV, weak mixing – Schwerdtfeger at Dec 07 ISOLDE workshop
- Coulex of (^{30,32}Mg and) ^{31}Mg – Reiter do
- Transfer d(^{30}Mg,^{31}Mg)p – Bildstein do
- Magnetic moments ^{31,33}Mg, COLLAPS – Yordanov et al, PRL 99 (2007) 212501
- Masses, MISTRAL – Lunney et al, Eur. Phys. J. A28 (2006) 129
- Level lifetimes – Mach et al, Eur. Phys. J. A25 (2005) 105
- Radii, beta-decay studies,...

Miniball Coulex, examples





$^{184\text{-}188}$Hg, autumn 2007

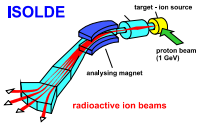
^{80}Zn (N=50) –

Van de Walle et al, PRL 99 (2007) 142501

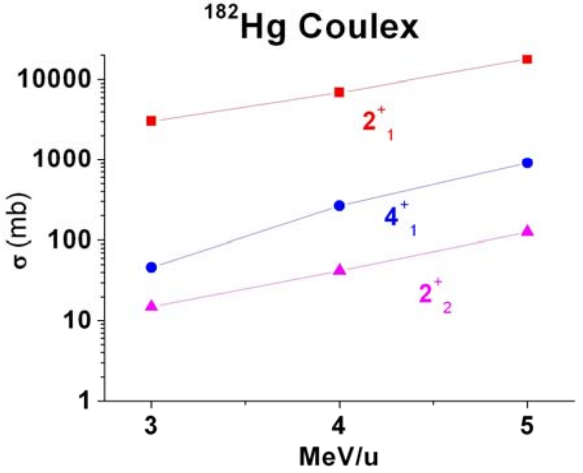
^{68,70}Cu (isomeric beams) –

Stefanescu et al, PRL98 (2007) 122701

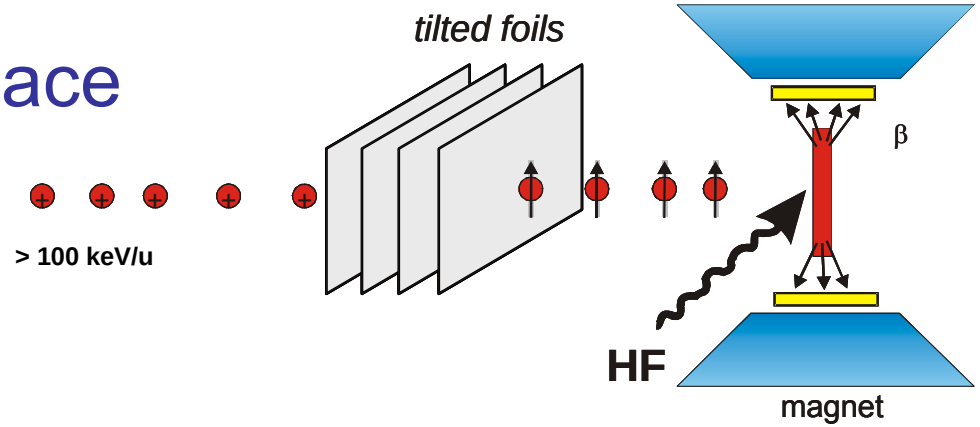
Aims of the upgrade



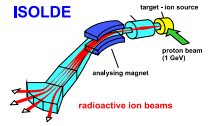
- Intensity
- Energy
  - Coulex for all RIB
  - Transfer reactions
- Efficiency
- Selectivity
- Beam “quality”
  - Reduced phase space
  - Bunching
- Polarization .....



low energy + accelerated

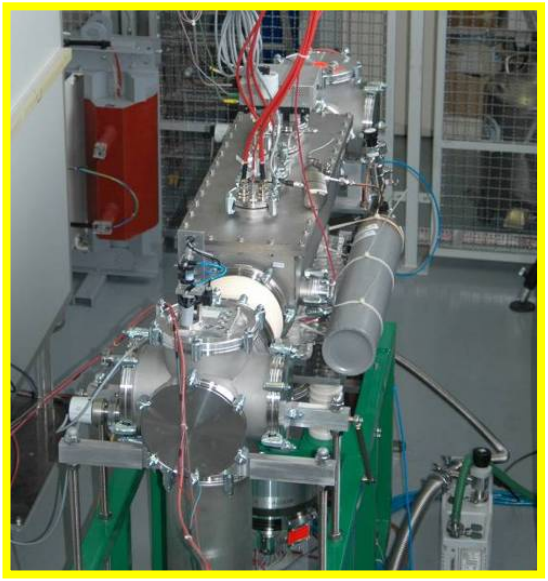


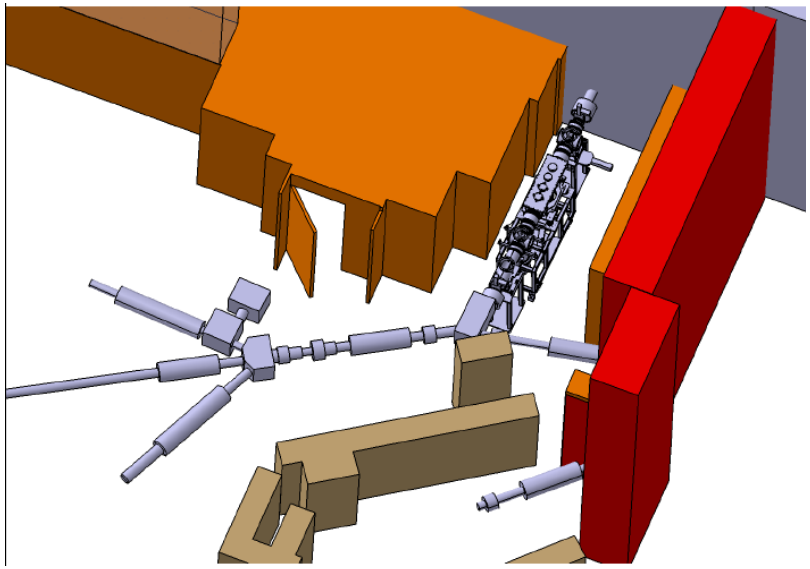
... already ongoing



RFQ cooler

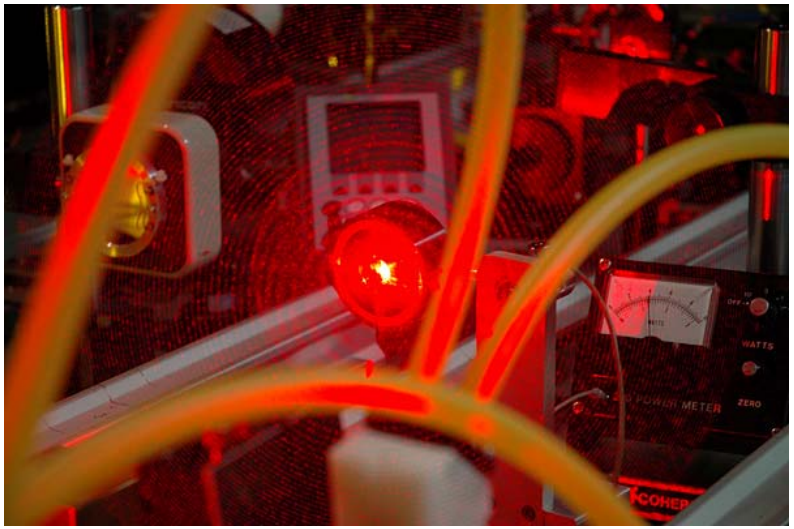
UK, JYFL, Mainz..





RILIS upgrade

Sweden (Wallenberg)

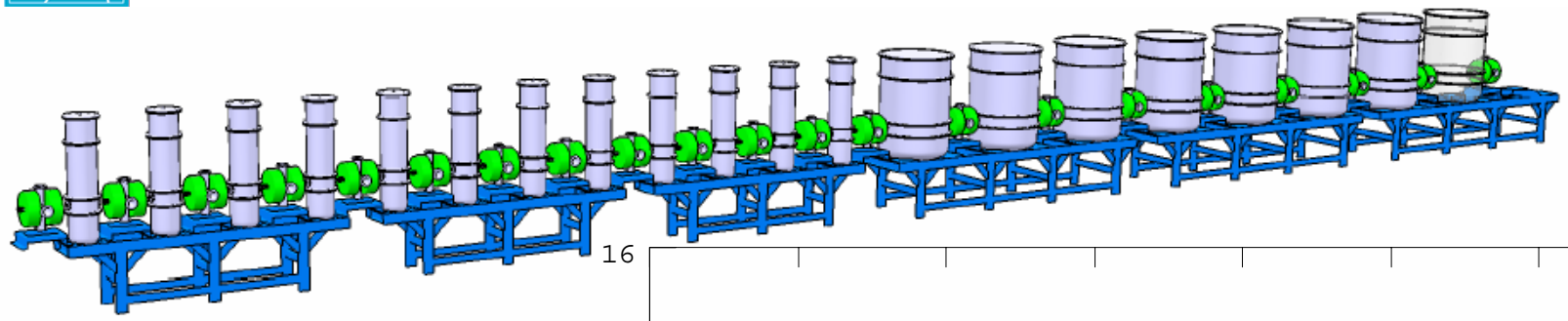


REX extension

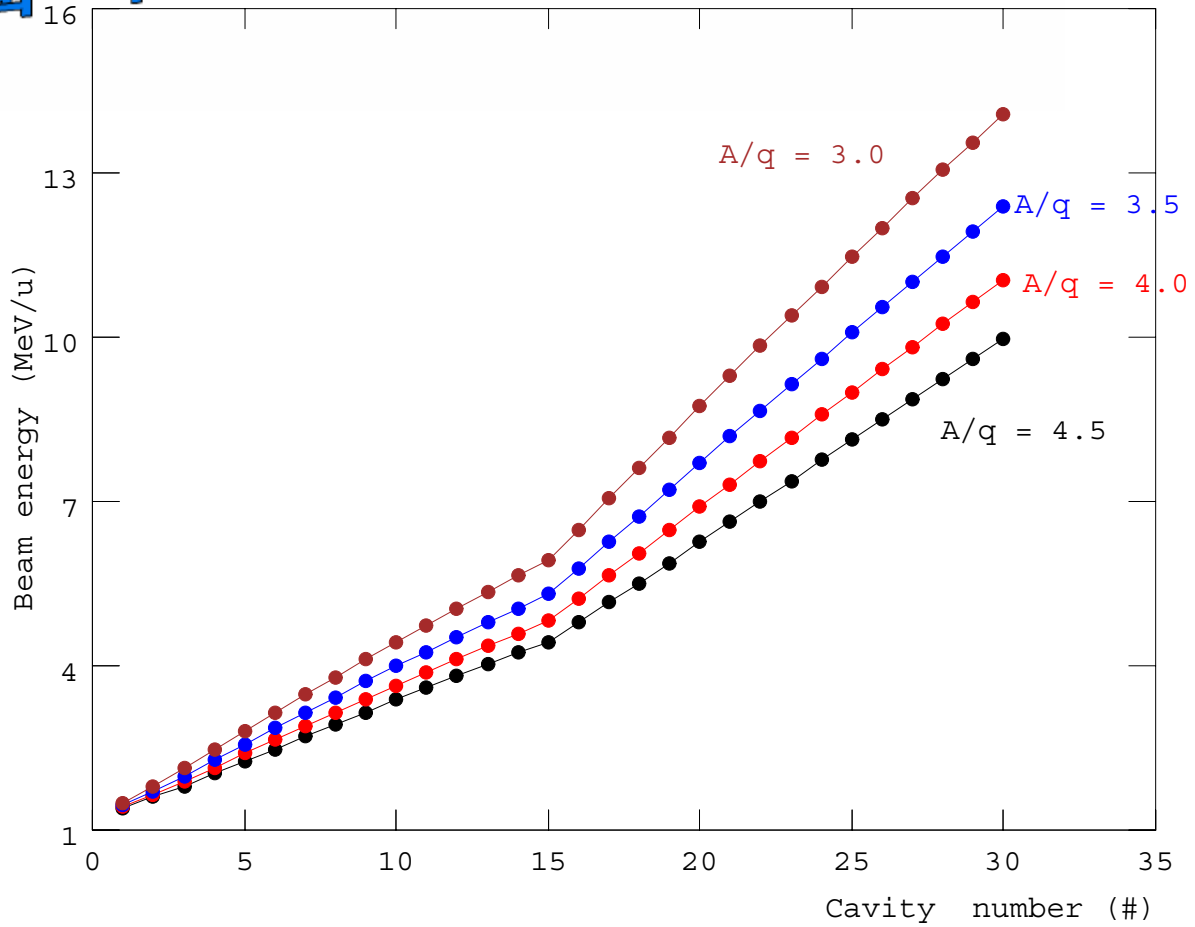
UK (Cockcroft Institute..), Leuven..

+ in CERN white paper “4. theme”

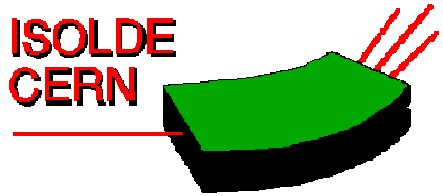
SC linac



Max energy for different A/q :



M. Pasini



Thanks to:

The ISOLDE Physics Group
The ISOLDE Technical Group
The ISOLDE Collaboration

Peter Butler

Mats Lindroos

http://hie-isolde.web.cern.ch/HIE-ISOLDE/

HIE-ISOLDE: the technical options - CERN-2006-013

HIE-ISOLDE: the scientific opportunities - CERN-2007-008